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THE PALEONTOLOGY AND STRATIGRAPHY OF THE PLEISTOCENE AT SIGNAL HILL, LONG BEACH, CALIFORNIA

BY

JAMES H. DELONG, Jr.

California Institute of Technology

SAN DIEGO, CALIFORNIA

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INTRODUCTION

Location

Signal Hill is located in the northern limits of the city of Long Beach, Los Angeles County, California, approximately two and a half miles north of the Pacific Ocean waterfront. It reaches an elevation of three hundred and sixty-four feet and is the highest point in a series of low-lying hills that extend from Seal Beach in Orange County, to the Dominguez Hills, approximately ten miles to the northwest. Signal Hill is a portion of the Long Beach oil field.

Review of Literature

Arnold (1, pp. 30-32) in his report on the marine Pleistocene at San Pedro, California, gave a brief but fairly detailed account of the Pleistocene stratigraphy and paleontology at Signal Hill. Arnold listed a fauna of one hundred and sixty species from the "Upper San Pedro" formation (Palos Verdes sands), but he found no fossils in the underlying sands and gravels. However, Arnold considered this latter group to be equivalent to his "Lower San Pedro" formation (San Pedro sands). So far as I know this is the only published report that has a detailed account of the Pleistocene at Signal Hill.

Eaton (5, p. 124) considered the Palos Verdes sands on Signal Hill as being equivalent in part to the warm-water Hall Canyon formation of Lower Pleistocene age, rather than Upper Pleistocene.

Grant and Gale (7, p. 43) suggested that the "Upper San Pedro" on Signal Hill might possibly belong to the basal warm-water Las Posas

* Contribution No. 305, Balch Graduate School of the Geological Sciences, California Institute of Technology, Pasadena, California.

zone instead of the Palos Verdes sands because the beds are deformed and there are two warm-water horizons in the Pleistocene instead of one.

Professor Tieje (7, p. 43) also suspected that the "Upper San Pedro" beds at Signal Hill belonged to the Las Posas zone.

Purpose of Report

I spent the summer of 1938 studying the stratigraphy and paleontology of the two Pleistocene formations exposed at Signal Hill. Special emphasis in this study was placed on the lower series of sands and gravels from which a large representative fauna was collected. Previous to this no fossils had been reported from this lower group of sediments. It seems desirable, therefore, to record the results of this investigation.

Acknowledgments

I wish to express my appreciation to Dr. W. P. Woodring of the United States Geological Survey, for suggesting the problem and for criticism and advice. Dr. W. P. Popenoe, Curator of Invertebrate Paleontology at the California Institute of Technology, has had general supervision of this paper during its preparation. He has offered many valuable suggestions regarding the faunal relations and stratigraphy of the Signal Hill formations. Mr. H. Hollis Reamer, Mr. John W. Christensen, and Mr. Robert J. Urick of the California Institute of Technology have rendered valuable assistance in the field. The Pleistocene collections of Southern California and the Golisch collection of Recent shells, both at the California Institute of Technology, were indispensable in making comparisons with the fossils collected at Signal Hill.

STRATIGRAPHICAL NOMENCLATURE

Before proceeding with a discussion of the geology of Signal Hill, it is perhaps advisable to give a brief discussion of the stratigraphical nomenclature used in this report.

Arnold (1) used the terms "Lower San Pedro" and "Upper San Pedro" for his formations of Lower and Upper Pleistocene age, respectively. Kew suggested, in work for the United States Geological Survey, the names "San Pedro" and "Palos Verdes" for Arnold's "Lower and Upper San Pedro" formations. These have been accepted by the United States Geological Survey and, accordingly, will be used in this report.

Stratigraphy

General Statement

The rocks exposed at the surface on Signal Hill are composed of loosely consolidated marine sands and gravels. They are divisible into two formations: (1) the Palos Verdes sands of Upper Pleistocene age and (2) the San Pedro sands of Lower Pleistocene age. The Lower Pleistocene sands are found in oil wells at all depths down to 1000 feet. No formations older than the San Pedro sands are known from surface exposures, but subsurface data show the Lower Pleistocene to be underlain unconformably by the Pico formation of Upper Pliocene age, approximately 1300 feet thick, which in turn is unconformably underlain by Lower Pliocene Repetto formation, which is approximately 2300 feet thick at Signal Hill and which contains most of the oil-producing horizons (9). These Pliocene sediments are more consolidated than the Pleistocene and consist of alternating beds of sand, sandy shale, and shale. Some of the wells below a depth of 5000 feet have entered a hard black shale which is believed to be Upper Miocene (2). The columnar section (Fig. 1) shows this succession in more detail.

San Pedro Sands

The San Pedro sands in the Signal Hill area consist of a series of fairly well-bedded, though locally cross-bedded, loosely consolidated marine silts, sands, and gravels. They are gray colored when fresh, but because of the many local brownish pockets and lenses, and the general tendency to weather out with a brown color, the series is easily distinguished by its brown color from the overlying gray Palos Verdes sands. The fragments vary from silt size up to four or five inches in diameter. The majority of these pebbles are well-rounded, slightly weathered, and of an assortment that seems to indicate their derivation from a possible quartz diorite region. A few rounded pebbles of shale were found in the coarser beds. The lithology of these fragments is very similar to the Miocene shale beds exposed in and around San Pedro. On the north slope of water Tank Hill (Fig. 3), in a small ravine about 200 feet east of the lowermost oil well is an outcrop of a well-consolidated gray silt—almost a shale. In lithology it closely resembles a portion of the Miocene shale exposed on the Palos Verdes Hills, but because of its stratigraphic position it is believed to be a consolidated lens of the San Pedro sands.

Although a good deal of lensing occurs, as is natural in a gravel

and sand series, the San Pedro sands as a whole, at least in the exposed portion, are fine-grained in the lower portion and coarsest in the uppermost part. This is the reverse of normal order of deposition but it may be explained by the fact that the surrounding uplands were probably undergoing initial diastrophic disturbances preparatory to the great Pacific Coast Pleistocene revolution.

On Water Tank hill the San Pedro sands are finer-grained and more firmly consolidated than on Signal Hill proper.

An exceedingly fossiliferous silt lens was found in the lower part of the exposed San Pedro sands in the old reservoir cut (Fig. 3).

The exposed portion of the San Pedro sands on Signal Hill is approximately 75 feet thick. As indicated in a previous paragraph, the well-core evidence tentatively places the thickness of the Lower Pleistocene succession of which the San Pedro sands are a part at approximately 1000 feet. Whether this section belongs to the San Pedro sands entirely, is not known.

The San Pedro sands are the core of Signal Hill and thus outcrop on all sides of the hill, wherever an artificial cut or small ravine has cut through the overlying Palos Verdes sands. The dips are variable but are usually steep, ranging from 15 to 40 degrees. In general, at any given point, the beds dip in the same direction as the slope of the hill.

Palos Verdes Sands

Resting unconformably on the tilted brown San Pedro sands at Signal Hill is a gray stratum of exceedingly fossiliferous, unconsolidated, marine gravel. The matrix varies from fine sand grains to pebbles three inches in diameter. Most of these pebbles are fresh, subangular to well-rounded, and of a heterogeneous assortment. However, no fragments of Miocene shale which are common to the Palos Verdes sands at San Pedro were found in the Signal Hill localities. The fossils are well preserved and may easily be removed from the matrix by hand. The gravel stratum varies from three inches to about two feet in thickness.

Overlying the fossiliferous gravel is a massive deposit of fine, gray, micaceous, unconsolidated sand. No fossils were found in it. The sand varies from two to over ten feet in thickness. It thickens to the south and west where it replaces or overlies the basal gravel. Arnold (1, p. 32) states

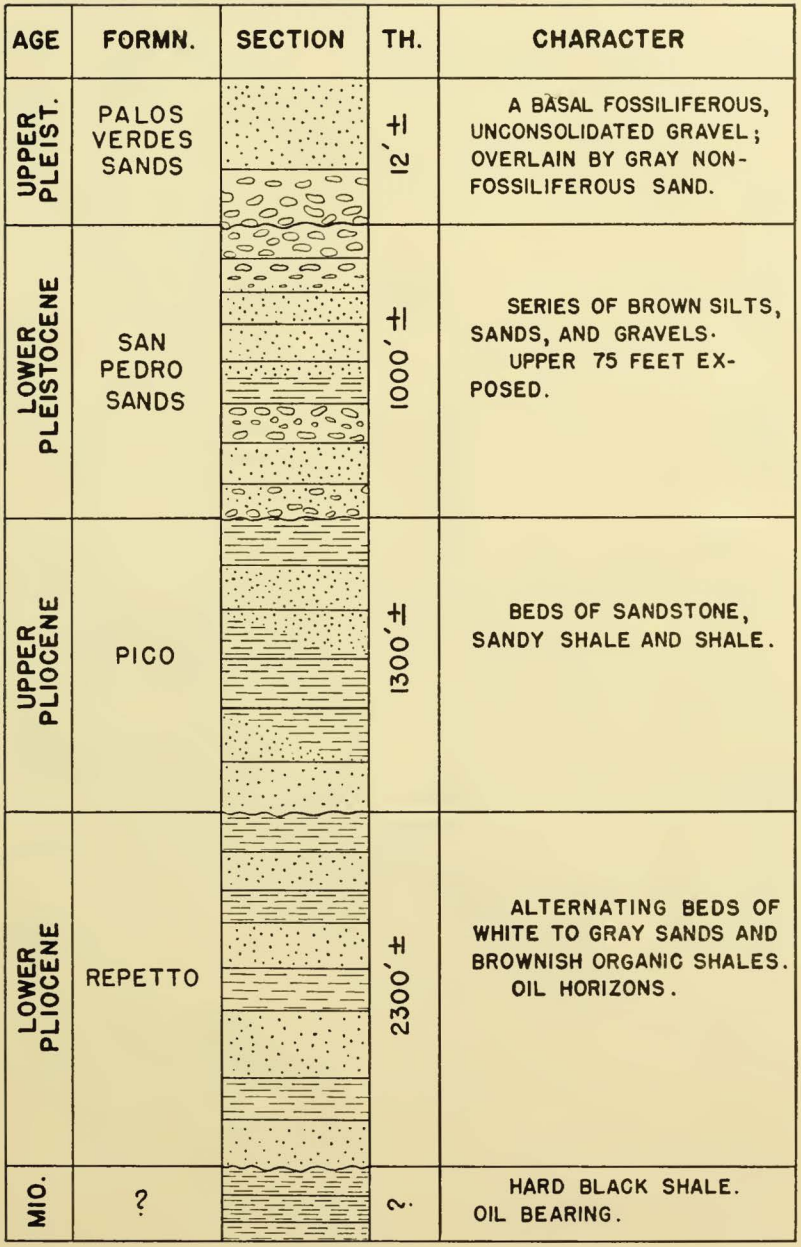

FIG. 1

GENERALIZED COLUMNAR SECTION
OF SURFACE AND SUBSURFACE FORMATIONS.
(NOT DRAWN TO SCALE)

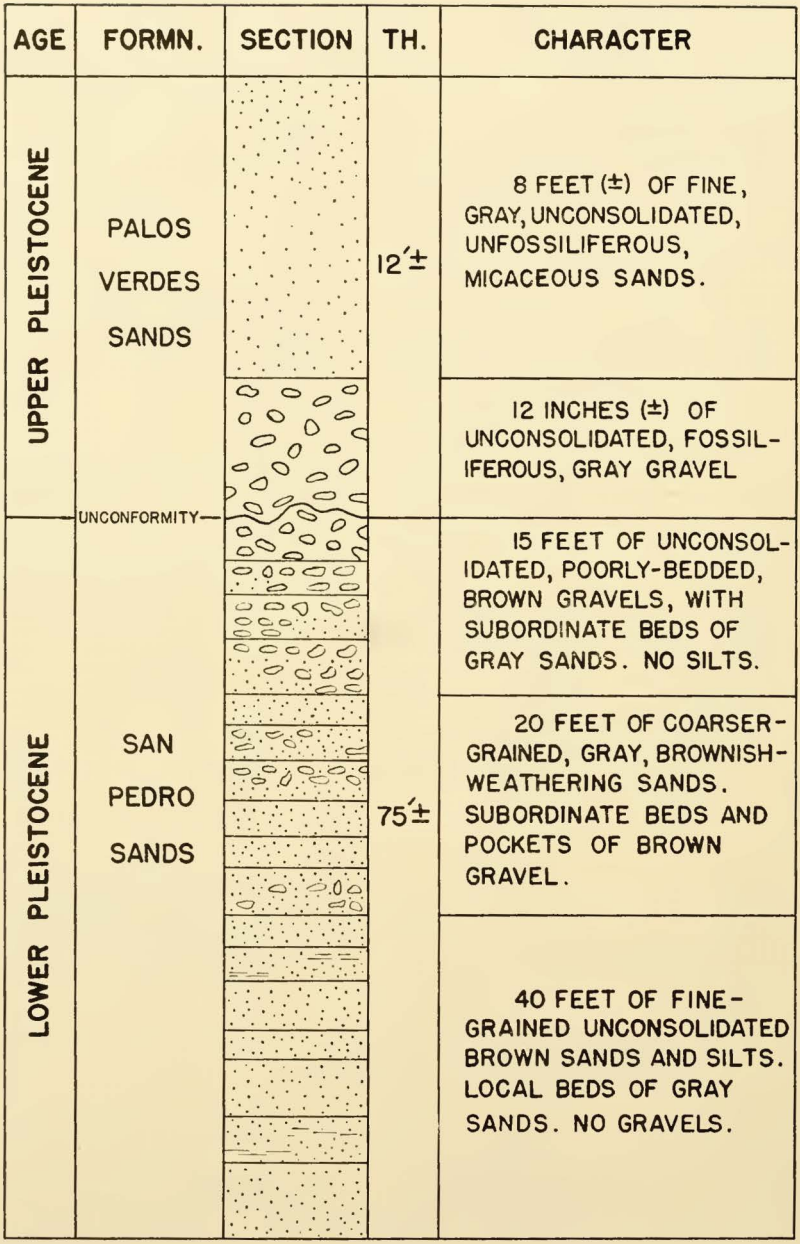

FIG. 2

COLUMNAR SECTION OF EXPOSED FORMATIONS
SIGNAL HILL AREA.

that the fifty feet of sand exposed in the sea cliff at Long Beach is a continuation of the Palos Verdes sands exposed on Signal Hill. Because of a covering of vegetation and a city ordinance against excavation, this statement could not be verified. It is probably a continuation, however, because of the fauna reported by Arnold and the dip in that direction on the south side of Signal Hill.

The basal gravel is fairly uniform in character wherever exposed except in the Cherry Avenue cut between East 23rd and Burnett Streets, where the pebbles are more weathered and the fossils are semi-cemented together by calcium carbonate—a coquina-like mass. The overlying sands are remarkably uniform in color, texture, composition and structure, wherever they are found in the Signal Hill region.

The Palos Verdes sands can always be easily recognized by their lithology and faunal content.

The Palos Verdes sands are absent from the northwest side of Signal Hill. This absence is probably due to erosion and possible patchy deposition of the sediments. On the east slope of Water Tank hill, in a dump, are Palos Verdes sediments and fossils. However, they are not in place and most likely were dumped there after being hauled from some other locality. Outside of this occurrence, the Palos Verdes sands are not present on this hill.

The dips are gentle and closely follow the slope of the hill both in direction and amount.

Overlying the Palos Verdes sands are about two to over twenty-five feet of dark brown sandy soil, the thickest part being on the crest of Signal Hill.

Paleontology

San Pedro Sands Fauna

GASTROPODA

Amphissa columbiana Dall
A. reticulata Dall
A. ventricosa Arnold
Bittium asperum (Gabb)
B. catalinense Bartsch
B. larum Bartsch
B. ornatissimum Bartsch
B. rugatum Carpenter
Bursa californica Hinds ?

Calliostoma canaliculatum (Martyn)
C. costatum (Martyn)
Cancellaria tritonidea (Gabb)
Clathurella conradiana Gabb
Conus californicus Hinds
Crepidula adunca Sowerby
C. excavata (Broderip)
C. nummaria Gould
C. onyx Sowerby
C. princeps Conrad
Epitonium indianorum (Carpenter)
Fusinus barbarensis (Trask)
Mangelia hecetae Dall and Bartsch
Mitrella carinata (Hinds) var. gausapata (Gould)
M. tuberosa (Carpenter)
Moniliopsis incisa (Carpenter)
Nassarius mendicus (Gould)
N. mendicus (Gould) var. cooperi (Forbes)
N. perpinguis (Hinds)
Natica clausa Broderip and Sowerby
Neptunea tabulata (Baird)
Neverita alta Dall
N. recluziana imperforata Dall
Olivella pedroana (Conrad)
Polinices lewisii (Gould)
Seila montereyensis Bartsch
Surculites carpenterianus (Gabb)
Terebra albocincta (Carpenter) var. pedroana Dall
Tritonalia barbarensis (Gabb)
T. lurida (Middendorff)
T. poulsoni (Carpenter)
Trophon eucymata Dall
T. multicostatus (Eschscholtz)
T. pacificus (Dall)
Turbonilla pedroana Dall and Bartsch
Turcica caffea Gabb
Turritella cooperi Carpenter

PELECYPODA

Botula diegensis Dall ?
Cardita ventricosa Gould
Clementia subdiaphana Carpenter
Corbula luteola Carpenter
Cryptomya californica (Conrad)
Gari edentula (Gabb)
Laevicardium corbis (Martyn)
L. quadragenarium (Conrad)

Lucina acutilineata Conrad
L. californica Conrad
L. nuttallii Conrad
L. tenuisculpta Carpenter
Macoma calcarea (Gmelin)
M. inquinata (Deshayes)
Nucula castrensis Hinds
Nuculana taphria (Dall)
Panope generosa Gould
Pecten hastatus Sowerby
P. islandicus Muller var. hindsii Carpenter
P. islandicus Muller var. jordani Arnold
P. latiauratus Conrad
P. multirugosus Gale
P. stearnsii Dall
P. sp.
Pododesmus macroschisma (Deshayes)
Psephidia cymata Dall
P. ovalis Dall
P. salmonea (Carpenter)
Saxicava arctica (Linnaeus)
Schizothaerus nuttallii (Conrad)
Solen sicarius Gould
Thracia undulata (Conrad)
Yoldia scissurata Dall

SCAPHOPODA

Dentalium neohexagonum Sharp and Pilsbry

Faunal Summary—San Pedro Sands

Total number of species	77
Pelecypoda	31
Gastropoda	45
Scaphopoda	1
Species living at San Pedro	55
Percentage of fauna	71
Species living only north of San Pedro	12
Percentage of fauna	16
Species living only south of San Pedro	6
Percentage of fauna	8
Species having greatest range north of San Pedro	14
Percentage of fauna	18
Species having greatest range south of San Pedro	4
Percentage of fauna	5
Species extinct	3
Percentage of fauna	4

Species of questionable habitat 3
Percentage of fauna 4

Faunal Relations—San Pedro Sands

The strata in which the fossils of the San Pedro sands at Signal Hill were found, were laid down in relatively shallow water. The medium-grained, tan and gray sands in which they were found are similar to the sands which are being deposited in depths from ten to twenty-five fathoms off Long Beach at the present time. The fauna of the San Pedro sands at Signal Hill is a cool-water fauna. This is evidenced by the higher percentages of cold-water affinities than warm. 16% of the species are now living only north of San Pedro and 18% of those that range north and south of San Pedro have a much more pronounced range north than south. This is at quite a variance with the 8% obtained for the forms now living only south of San Pedro and 5% for those with a pronounced southerly range. The presence of the southern forms in the San Pedro sands indicates a temperate climate, probably somewhat similar to the present climate of the Pacific Northwest. That this cool temperate aspect was climatic rather than facies is shown by the relatively constant ratio between northern and southern forms wherever the San Pedro sands are found.

Palos Verdes Sands Fauna

GASTROPODA

Acanthina spirata (Blainville)
Acmaea insessa (Hinds)
Acteon punctocaelatus (Carpenter)
Amphissa columbiana Dall
A. versicolor Dall
Bullus punctulatus (Adams)
Calliostoma canaliculatum (Martyn)
C. gemmulatum Carpenter
C. tricolor Gabb
Calyptraea mamillaris Broderip
Ceritidea californica (Haldeman)
Conus californicus Hinds
Crepidula adunca Sowerby
C. crepidula lessoni Broderip
C. excavata (Broderip)
C. nummaria Gould
C. onyx Sowerby
C. sp.

Crucibulum spinosum (Sowerby)
Diodora aspera (Eschscholtz)
Epitonium indianorum (Carpenter)
Hyalina californica (Tomlin)
Lacuna unifasciata Carpenter
Lora sp.
Lucapinella callomarginata (Carpenter)
Mangelia hecetae Dall and Bartsch
M. variegata Carpenter
Megatebennus bimaculata (Dall)
Melampus olivaceous Carpenter
Melanella hastata (Sowerby)
M. micans (Carpenter)
Mitrella carinata (Hinds)
M. carinata (Hinds) var. gausapata (Gould)
M. tuberosa (Carpenter)
Moniliopsis incisa (Carpenter)
Nassarius californianus (Conrad)
N. cerritensis (Arnold)
N. fossatus (Gould)
N. mendicus (Gould)
N. mendicus (Gould) var. cooperi (Forbes)
N. perpinguis (Hinds)
N. tegula (Reeve)
Neverita alta Dall
N. recluziana imperforata Dall
Olivella biplicata (Sowerby)
O. pedroana (Conrad)
Polinices lewisii (Gould)
Purpura festiva (Hinds)
P. nuttallii (Conrad)
Retusa carinata (Carpenter)
R. culcitella (Gould)
Tegula ligulata (Menke)
Terebra albocincta (Carpenter) var. pedroana Dall
Tricolia compta (Gould)
T. pulloides (Carpenter)
Tritonalia lurida (Middendorff)
T. poulsoni (Carpenter)
Turbonilla pedroana Dall and Bartsch
T. torquata (Gould)
T. tridentata (Carpenter)
Turritella cooperi Carpenter
Volvulella cylindrica (Carpenter)

PELECYPODA

Amiantis callosa (Conrad)

Anomia peruviana d'Orbigny
Apolymetis biangulata (Carpenter)
Chama pellucida Broderip
Corbula luteola Carpenter
Crassinella branneri (Arnold)
Cryptomya californica (Conrad)
Cumingia lamellosa Sowerby
Donax californicus Conrad
D. gouldii Dall
Dosinia ponderosa (Gray)
Laevicardium procerum (Sowerby)
L. quadragenerium (Conrad)
L. substriatum (Conrad)
Lima dehiscens Conrad
Lucina nuttallii Conrad
Macoma indentata Carpenter
M. moesta (Deshayes) var. acolasta Dall
M. nasuta (Conrad)
M. secta (Conrad)
Mactra californica Conrad
M. elegans Sowerby
M. hemphilli Dall
M. nasuta Gould
M. planulata Conrad
Mya cancellata Conrad
Nucula exigua Sowerby
Nuculana taphria (Dall)
Ostrea lurida Carpenter
Pecten gibbus (Linnaeus) var. circularis Sowerby
P. latiauratus Conrad
P. multirugosus Gale
Periploma planiuscula Sowerby
Petricola carditoides (Conrad)
P. denticulata Sowerby
Pholas gabbi (Tryon)
Pitar squalidus (Sowerby)
Pododesmus macroschisma (Deshayes)
Pseudochama exogyra (Conrad)
Sanguinolaria nuttallii Conrad
Schizothaerus nuttallii (Conrad)
Semele decisa (Conrad)
S. pulchra (Sowerby)
Tagelus californianus (Conrad)
Taras parilis (Conrad) var. sericatus (Reeve)
Tellina bodegensis Hinds
T. buttoni Dall
T. meropsis Dall

Tivela stultorum (Mawe)
Venerupis staminea (Conrad)
V. staminea (Conrad) var. laciniata (Carpenter)
Venus fluctifraga Sowerby
V. gnidia Broderip and Sowerby
V. purpurissata Dall
Volsella recta (Conrad)
Yoldia cooperi Gabb

SCAPHOPODA

Dentalium neohexagonum Sharp and Pilsbry

CRUSTACEA

Balanus concavus Bronn
Cancer sp.

Faunal Summary—Palos Verdes Sands

Total number of species	119
Pelecypoda	56
Gastropoda	60
Scaphopoda	1
Crustacea	2
Species living at San Pedro	91
Percentage of fauna	77
Species living only north of San Pedro	2
Percentage of fauna	1
Species having greatest range north of San Pedro	5
Percentage of fauna	4
Species living only south of San Pedro	17
Percentage of fauna	14
Species having greatest range south of San Pedro	31
Percentage of fauna	26
Species extinct	2
Percentage of fauna	1
Species of questionable habitat	3
Percentage of fauna	2

Faunal Relations—Palos Verdes Sands

The fauna of the Palos Verdes sands at Signal Hill is southerly in character and represents a fauna that today is living several hundred miles south of San Pedro. Not only is there a relatively large percentage of the species now living only south of San Pedro (14%), but also many of those that are living at San Pedro have a much greater range to the south (26%) than the north (4%). Those northern forms present are very few and rare. The fauna may be said to be semi-tropical, as

evidenced by the presence of such forms as *Retusa carinata*, *Bulla punctulatus, Calliostoma gemmulatum, Laevicardium procerum,* and *Mactra hemphilli.*

The fauna is one that was probably deposited in shallow water under fairly rapid changing conditions. The faunal assemblage indicates a fauna that would be found on a low, sandy coast.

CHECK LIST OF FOSSILS COLLECTED AT SIGNAL HILL

In the following check list of fossils from the Pleistocene at Signal Hill, the specific and generic nomenclature generally follows that of Grant and Gale (7). The exceptions to this rule are that of *Venus purpurissata* Dall, *Amphissa reticulata* Dall, *Crepidula crepidula lessoni* (Broderip) *Neverita alta* Dall, and *Neverita recluziana imperforata* Dall. *V. purpurissata, A. reticulata,* and *C. crepidula lessoni* are not listed by Grant and Gale. They state (7, p. 802) that *N. alta* and *N. recluziana imperforata* are the same species. However, the specimens found on Signal Hill are distinct. Accordingly, the classification of Dall is used.

The letter R indicates that a species is rare in a given locality, there having been three or less specimens. The letter C denotes "common" (four to ten specimens), and the letter A indicates "abundant", or that 10 or more specimens were found per locality. The presence of species in localities not collected by the author is indicated by the letter "P." In the column marked "Living", species now found living only south of San Pedro are indicated by an S. Species living only north are designated by the letter N. Species that range north and south are indicated by an X. Xn means a very pronounced northern range as compared with that of the south; Xs is vice versa. E indicates that the species is extinct. The present range of species was taken from Grant and Gale (7).

The column marked Las Posas (7, p. 42) includes the species common to Signal Hill and the calcareous beds and marls exposed at Lomita Quarry, Hilltop Quarry, and Second Street, San Pedro. The list of Las Posas fossils was taken from Clark (8, check list). The next four columns belong to the Timms Point horizon. Deadman Island and Second Street are locality names, while Zone 1 and Zone 2 are the two faunal zones present at the type locality at Timms Point, San Pedro. Species common to these localities and those of Signal Hill are accordingly listed under their proper headings. These fossils were

28,843

LOWER PLEISTOCENE — UPPER PLEISTOCENE — Palos Verdes Sands

	Timms Point					San Pedro Sands			Signal Hill								
	Signal Hill	Lay Point	Deadman Island	Second Street	Zone 3	Deadman Island	San Pedro Bluff	Nob Hill	Cherry Ave.	Reservoir Ave.	Hill St. and Walnut Ave.	Deadman Island	San Pedro Bluff	San Pedro Gravel	Lomita
GASTROPODA															
Acanthina spirata (Blainville)						P	P		B	A	C	P	P	P	X
Acmaea mesna (Hinds)		P	P		P	P	P				P	P	P	P	Xs
Acteon punctocaelatus (Carpenter)							P	P		B			P		Xs
Amphissa columbiana Dall	P					P				B			P		M
A. reticulata Dall	P	P	P	P	P										M
A. ventricosa Arnold	P														E
A. versicolor Dall						P					R	P	P	P	X
Batium asperum (Gabb)	P	P	P		P	P							P	P	X
B. catalinense Bartsch	P	P			P			P							X
B. larum Bartsch	P				P										X
B. ornatissimum Bartsch	C	P			P	P		P							X
B. rugatum Carpenter	A	P		P		P	P	P					P	P	X
Bullus punctulatus (Adams)										C	B	P	P	P	S
Bursa californica Hinds	B											P	P	P	X
Calliostoma canaliculatum (Martyn)	C	P	P	P	P	P	P	P	P		P	P	P	P	Xm
C. costatum (Martyn)	P	P	P			P	P	P					P	P	Xm
C. gemmulatum Carpenter									P	B			P	P	S
C. meolae Gabb										B			P	P	S
Calyptraea mamillaris Broderip					P		P	P		B			P	P	X
Cancellaria tritonidea Gabb	B														E
Cerithidea californica (Haldeman)						P	P	P	C	P	P	P	P		Xs
Clathurella conradiana Gabb	P						P	P							X
Cunia californica Hinds	A	P	P	P	P	P	P	P	P	A	A	A	P	P	P	Xs
Crepidula adunca Sowerby	R	P			P		P	P	C	P	C	P	P	P	X
C. crepidula lessoni Broderip										B					P
C. excavata (Broderip)	B								P	A	A	A			X
C. nummaria Gould	R	P			P	P	P	P		P		P	P	P	Xs
C. onyx Sowerby	C						P	P	A	C	A	P	P		Xs
C. princeps Conrad	P				P										E
C. sp.										B					P
Crucibulum spinosum (Sowerby)							P		C	C	C	P	P	P	Xs
Diodora aspera (Eschscholtz)					P		P	P		R		P	P	P	X
Epitonium indianorum (Carpenter)	R		P	P	P	P	P	P	E		R	P	P	P	X
Fusinus barbarensis (Trask)	C	P	P		P	P	P					P	P	P	Xm
Haminea californica (Tomlin)											R				S
Lacuna unifasciata Carpenter											W				S
Lora sp.									B						P
Lucapinella callomarginata (Carpenter)						P	P	P		R			P	P	X
Mangelia hecetae Dall and Bartsch	C					P					C			P	Xs
M. variegata Carpenter						P							P		X
Megastrebersia bimaculata (Dall)						P	P	P		P	A		P		Xs
Melampus olivaceous Carpenter										P	P	P			S
Melanella hastata (Sowerby)						P						P			X
M. micans (Carpenter)						P	P					P		P	X
Mitrella carinata (Hinds)						P	P		C		C	P	P	P	X
M. carinata (Hinds) var. gausapata (Gould)	A	P	P	P	P	P	P	P	P	C		P	P	P	X
M. rubensis (Carpenter)	A	P			P		P	P	P	C	P	P	P	P	Xm
Monilispira incisa (Carpenter)	R					P	P	P	R	C	C				S
Nassarius californianus (Conrad)						P			P	C	C	P	P		X
N. cerritensis (Arnold)									C	A	A	P	P	P	X
N. fossatus (Gould)						P	P	P	A	A	A	P	P	P	Xm
N. mendicus (Gould)	A	P	P	P	P	P	P	P	P	A	A	C	P	P	P	X
N. mendicus (Gould) var. cooperi (Forbes)	C	P	P	P	P	P	P	P	H		R	P	P	P	X
N. perpangus (Hinds)	A	P	P	P	P	P	P	P	P	A	A	A	P	P	P	Xm
N. tegula (Reeve)						P	P	P	E			P	P	P	Xm
Nassa clausa Broderip and Sowerby	C	P	P	P	P	P	P								X
Neptunea tabulata (Baird)	C	P	P	P	P	P	P	P							X
Neverita alta Dall	A	P	P	P	P	P	P	P		C	C	P	P	P	X
N. reclusiana imperforata Dall								A	A	C					X
Olivella biplicata (Sowerby)		P	P	P	P	P	P	P	A	C	R	P	P	P	Xm
O. pedroana (Conrad)	C	P	P	P	P	P	P	P	A	C	A	P	P	P	Xs
Polinices lewisii (Gould)	C	P		P	P	P		P	R	R		P	P	P	Xs
Purpuza festiva (Hinds)						P			B		B	P	P	P	S
P. nuttalli (Conrad)										H		P		E	Xm
Retusa cancata (Carpenter)									B						X
R. culcitella (Gould)		P		P	P		P	P		B	B	P	P	P	Xs
Scala montereyensis Bartsch	R					P	P	P							Xs
Surculites carpenterianus (Gabb)	C											P	P	P	Xs
Tegula lajulata (Menke)								P	C	C					Xs
Terebra alboconcta (Carpenter) var pedroana Dall	R					P	P		C	R	C	P	P	P	Xs
Tricolia compta (Gould)						P	P		C	H	A	P			Xm
T. pullorles (Carpenter)		P			P					B					N
Tritonalia barbarensis (Gabb)	R	P			P		P	P							Xs
T. lurida (Middendorff)	R					P		P		R				P	P
T. poulsoni (Carpenter)	R					P	P		P	C	R	P	P	P	Xm
Trophon eurymata Dall	R														X
T. multocostatus (Eschscholtz)	R		P		P			P							Xm
T. pacificus (Dall)	R		P		P		P						P		S
Turbonilla pedroana Dall and Bartsch	R				P		P	P	R				P		X
T. torquata (Gould)						P	P				C				Xs
T. tridentata (Carpenter)						P	P				R				X
Turcica caffea Gabb	R		P		P		P								Xs
Turritella cooperi Carpenter	A	P	P	P	P	P	P	P	C	R	B	P	P	P	X
Volvulella cylindrica (Carpenter)						P	P	P			R				Xm
SCAPHOPODA															
Dentalium neohexagonum Sharp and Pilsbry	A	P	P		P	P	P	P	A	A	A	P	P	P	Xs
PELECYPODA															
Amiantis callosa (Conrad)									A	A	A		P		Xs
Anomia peruviana d'Orbigny						P	P		C	A	C		P	P	Xs
Apolymetis biangulata (Carpenter)						P			C	A	A				X
Botula diegensis Dall	R					P					A				P
Cardita ventricosa Gould	A	P	P	P	P	P	P		P						Xm
Chama pellucida Broderip	P					P				R	B	P	P	P	Xs
Clementia subdiaphana Carpenter	C					P									Xm
Corbula luteola Carpenter	A					P	P			C	B		P		Xs
Crassinella brannerii (Arnold)									R	B			P		Xs
Cryptomya californica (Conrad)	R								A	A	A	P	P	P	X
Cumingia lamellosa Sowerby							P				B	P	P	P	Xs
Donax californicus Conrad						P	P					R			Xs
D. gouldii Dall						P	P		C	C	A	P	P	P	Xs
Dosinia ponderosa (Gray)										B					S
Gari edmulia (Gabb)	B												P		Xm
Laevicardium corbis (Martyn)	R	P		P	P	P	P	P				P	P	P	Xm
L. procerum (Sowerby)									C	A	A				S
L. quadragenarium (Conrad)	C	P			P	P		P	R	R	C		P		Xs
L. substriatum (Conrad)										B					S
Lima dehiscens Conrad										R					Xs
Lucina acutilineata Conrad	A	P	P	P	P	P	P	P							X
L. californica Conrad	R	P	P	P	P	P	P	P							Xs
L. nuttalli Conrad	R			P	P	P	P	P	A	A	C				Xs
L. tenuisculpta Carpenter	C	P		P	P		P	P							X
Macoma calcarea (Gmelin)	C	P	P	P	P	P	P	P		P					Xm
M. indentata Carpenter								P			R		P		X
M. inquinata (Deshayes)	R				P		P	P				P	P	P	M
M. moesta (Deshayes) var. acolasta Dall											R				E
M. nasuta (Conrad)						P		P	B		N	P	P	P	X
M. secta (Conrad)						P	P		B	R		P	P	P	X
Macrra californica Conrad										R			P		Xs
M. elegena Sowerby															P
M. hemphilli Dall											B	C			S
M. nasuta Gould										B					P
M. planulata Conrad						P	P	P	A	A	A	P	P	P	Xs
Mya cancellata Conrad										R		P	P	P	X
Nucula castrensis Hinds	A	P	P	P	P	P	P	P	P						Xm
N. exigua Sowerby						P	P		C	A	A		P		Xs
Nuculana taphria (Dall)	A	P	P	P	P	P	P	P	P	B	C	P	P	P	Xs
Ostrea lurida Carpenter						P	P	P	A	A	C		P	P	X
Panope generosa Gould	C	P	P	P	P	P	P								X
Pecten gibbus (Lamarck) var. circularis Sowerby									C	C	C				P
P. hastatus Sowerby	A	P	P	P	P	P	P		P					P	Xm
P. islandicus Muller var. hindsi Carpenter	R	P	P		P										Xm
P. islandicus Muller var. jordani Arnold	R		P	P	P	P	P		P						P
P. latiauratus Conrad	A	P			P		P	P	A	A	A	P	P	P	X
P. multirugosus Gale	C					P		P		B			P	P	X
P. stearnsi Dall	R			P											E
P. sp.	R														P
Periploma planiuscula Sowerby									R	B	B	P	P	P	Xs
Petricola carditoides (Conrad)						P		P	R	H		P	P	P	X
P. denticulata Sowerby						P			C	B	C				E
Pholas gabbi (Tryon)										H					Xm
Pitar squalidus (Sowerby)									E						S
Pseudoferussa macroschisma (Deshayes)	B	P								R		P	P	P	X
Psephidia cymata Dall	R	P		P	P	P									X
P. ovalis Dall	C	P		P											Xm
P. salmonea (Carpenter)	R				P		P	P							Xm
Pseudochama exogyra (Conrad)									B		R		P		Xs
Sanguinolaria nuttallii Conrad		P			P	P		P	R				P		Xs
Saxicava arctica (Linnaeus)	R							P					P		X
Saxidomus nuttallii Conrad		P	P		P		P	P	R	H		P	P	P	Xs
Schizothaerus nuttallii (Conrad)	R				P			P		R	R	P	P	P	X
Semele decora (Conrad)						P				C	C	P	P	P	S
S. pulchra (Sowerby)									R	A	A		P		Xs
Solen sicarius Gould	C	P	P	P	P	P	P	P				P	P	P	X
Tagelus californianus (Conrad)									L	L		P	P	P	Xm
Tarea pardia (Conrad) var. sericatus (Reeve)									R	t	R		P		Xs
Tellina bodegensis Hinds						P	P	P		B		P	P	P	X
T. buttoni Dall										B					X
T. meropus Dall		P		P					P	C	R				S
Thracia undulata (Conrad)	R					P			P						Xs
Tivela stultorum (Mawe)							P	P	R	R	R	P	P	P	X
Venerupis staminea (Conrad)						P	P	P	R		C	P	P	P	X
V. staminea (Conrad) var. lacinata (Carpenter)									H		P				Xm
Venus fluctifraga Sowerby									R	R			P		S
V. gnidia Broderip and Sowerby									C	B			P		S
V. purpurascens Dall										R					
V. succincta Valenciennes									A	C	C	P	P	P	X
Volsella recta (Conrad)						P			R			P	P		X
Yoldia cooperi Gabb									H				P		Xm
Y. scissurata Dall	R	P			P	P	P		R						N
CRUSTACEA															
Balanus concavus Bruun							P				A	P	P	P	
Cancer sp.											R				

also taken from Clark's check list (8). The San Pedro sands are subdivided into three, Deadman Island, San Pedro Bluffs, and Nob Hill, localities around San Pedro in which they are exposed. Arnold's (1, check list) lists were consulted for Deadman Island and San Pedro Bluffs, while Oldroyd (4) was used for Nob Hill. Cherry Avenue, Hill Street and Temple Avenue, and Raymond Avenue are the three localities on Signal Hill at which the Palos Verdes sands outcrop. Crawfish George's, and the San Pedro Bluffs—the lumber yard of Arnold (1, p. 27)—are the localities in which the Palos Verdes sands are exposed in the San Pedro region. The fossils present in the two latter localities were taken from Arnold (1, check list).

Collecting Localities

The following is a list of California Institute of Technology collecting localities at Signal Hill (Fig. 3).

1350 In a large oil well cut, 100 feet N 45 E of the northeast corner at the intersection of Hill Street and Temple Avenue.

1348 West end of the south face of a low hill on the east side at the north end of Raymond Avenue.

1349 The west face of a road cut on the east side of Cherry Avenue, 75 feet north of Cherry Avenue and East 23rd Street intersection.

1351 In the base of a hill cut 15 feet north of the center point of the top of the north side of the westernmost old cement reservoir between California and Orange Avenues on the west and east and Willow and Spring Streets on the south and north, respectively.

Correlation

San Pedro Sands

Before proceeding with a discussion of the correlation of the Lower Pleistocene fauna at Signal Hill with the Pleistocene assemblages at San Pedro, a brief description of the stratigraphy at San Pedro seems in order.

The basal marine Pleistocene strata of the San Pedro are the calcareous beds and marls exposed at Second Street, Hilltop Quarry, and Lomita Quarry. Grant and Gale (7, p. 42) refer these to the Las Posas zone and they contain a warm-water fauna. Overlying the Las Posas zone unconformably is the Timms Point zone, the beds of which are exposed at Timms Point and at Second Street. Clark (8, p. 41) recognizes two zones in this horizon; a lower which contains a transitional

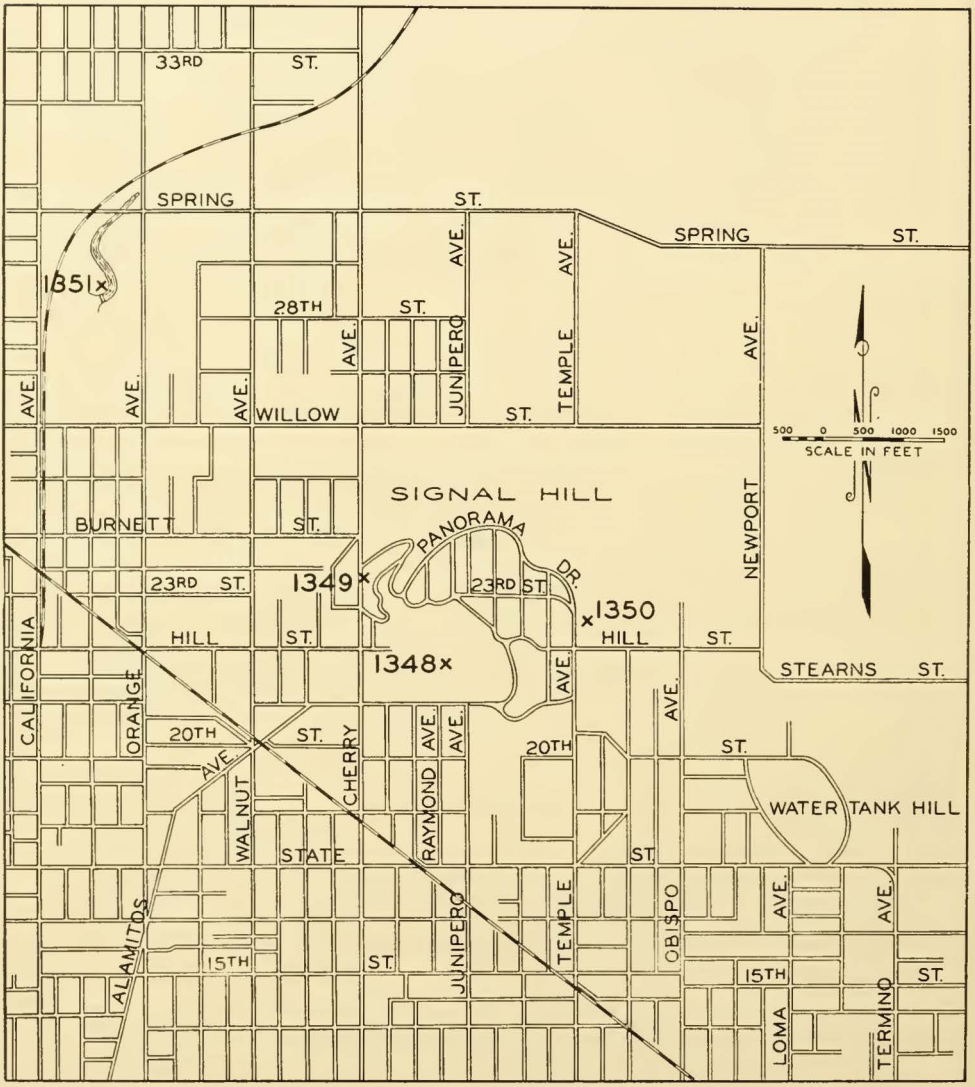

Fig. 3. Sketch map of a portion of the city of Long Beach, California, showing fossil localities at Signal Hill.

(Adapted from U. S. Geol. Survey, Long Beach and Clearwater Quadrangles)

fauna and the upper which is a decidedly cool-water fauna. Grant and Gale (7, p. 42) consider this horizon to be a separate formation, but Dr. W. P. Woodring of the United States Geological Survey, suggests in a personal communication that the Timms Point horizon is merely a deep water facies of the overlying San Pedro sands. Unconformably above the Timms Point beds are the San Pedro sands with their more temperate water fauna. This horizon is exposed at Second Street and at Nob Hill. Truncating this entire Lower Pleistocene section are the Palos Verdes sands of Upper Pleistocene age. The beds are exposed at many places around San Pedro, a few of which are Crawfish George's, Beacon Avenue, and around the San Pedro Bluff. The fauna is decidedly a warm-water fauna.

The entire section was formerly exposed on Deadman Island in Los Angeles harbor before the island was blasted away in the process of harbor improvement.

A correlation will now be attempted between the Signal Hill deposits and those of the San Pedro region. The correlation is based on the following points of evidence:

1. Total percentage of Signal Hill species present in the various horizons in the San Pedro district.
2. The percentage of Signal Hill species found only at Signal Hill and one locality around San Pedro.
3. The percentage of abundant Signal Hill forms present abundantly in the San Pedro horizons.
4. Percentage of extinct species.
5. Cool or warm-water character of fauna.
6. Similarities in the faunas as indicated by comparison with the California Institute of Technology Pleistocene collections.

The total percentage present in other horizons is:

Las Posas zone	53
Deadman Island (Timms Point horizon)	39
Second Street (Timms Point horizon)	36
Zone 1 (Timms Point horizon)	63
Zone 2 (Timms Point horizon)	43
Deadman Island (San Pedro sands)	71
San Pedro Bluffs (San Pedro sands)	45
Nob Hill Cut (San Pedro sands)	52

The above results suggest that the Signal Hill Lower Pleistocene deposits are equivalent either to the San Pedro sands or the Timms Point horizon. The Las Posas zone can be disregarded, although it has a fairly high percentage of species present at Signal Hill. The Las Posas

zone fauna lived in warm-water, the Signal Hill fauna in cool-water. The faunal assemblages are also quite dissimilar.

Signal Hill species found only at the following localities are:

Deadman Island (Timms Point horizon)	0
Second Street (Timms Point horizon)	1
Zone 1 (Timms Point horizon)	11
Zone 2 (Timms Point horizon)	2
Deadman Island (San Pedro sands)	18
San Pedro Bluffs (San Pedro sands)	5
Nob Hill Cut (San Pedro sands)	5

This limits the possibilities to Zone 1, Timms Point, and Deadman Island, San Pedro sands. The other four localities can be neglected because of their low values.

The percentage of abundant Signal Hill species abundant in Zone 1, Timms Point, and Deadman Island, San Pedro sands is:

Zone 1 (Timms Point horizon)	22
Deadman Island (San Pedro sands)	34

It will be noticed that the Deadman Island San Pedro sands percentage values are highest throughout these three points of evidence, and thus suggest that the Signal Hill Lower Pleistocene is equivalent to the San Pedro sands.

For further verification of this evidence the extinction values were consulted. Clark (8, p. 32) reported the Timms Point extinction as being 8.8%. The Signal Hill fauna is in sharp contrast to this in being at 4%, which in turn is nearer that of the San Pedro sands.

As a final check, the California Institute of Technology Pleistocene collections of southern California were studied. These collections show that the characteristic Zone 1 Timms Point fossils, such as *Turritella jewettii, Pecten caurinus, Thracia trapezoides, Nuculana minuta praecursor, Protocardia centifilosa, Cardita barbarensis* are not found on Signal Hill. On the other hand, the Signal Hill species closely resemble those of the San Pedro sands at Deadman Island.

Hence, all this evidence leads to the conclusion that the exposed Lower Pleistocene deposits on Signal Hill are equivalent to the San Pedro sands horizon of the San Pedro region, and equivalent in facies to the San Pedro sands formerly exposed on Deadman Island. Each point used as evidence in this correlation is not by itself conclusive but when the six give the same trend, fairly accurate and safe conclusions can be drawn.

Palos Verdes Sands

The warm-water deposits which overlie the San Pedro sands on Signal Hill are equivalent to the Palos Verdes sands of Upper Pleistocene age in the San Pedro region. The fauna is also probably of the same facies as that found in the San Pedro bluffs near the old lumber yard of Arnold's report (1). The evidence for this correlation is based on the remarkable similarities in the forms present at both localities and the similar sub-tropical aspect of the two faunas.

At first a possible correlation might be attempted between the Signal Hill Palos Verdes sands and the beds of the warm-water beds of the Las Posas zone because of the warm-water aspect of both faunas. However, Dr. W. P. Woodring (7, p. 40) has shown that the Las Posas at San Pedro underlies beds that are equivalent to the sands and gravels that underlie the warm-water beds on Signal Hill.

No long range correlations were attempted, but from the collection of Spanish Bight, San Diego, fossils at the California Institute of Technology, it is evident that the Signal Hill Palos Verdes sands fauna is very similar to it. Hence, it is considered to be of the same facies.

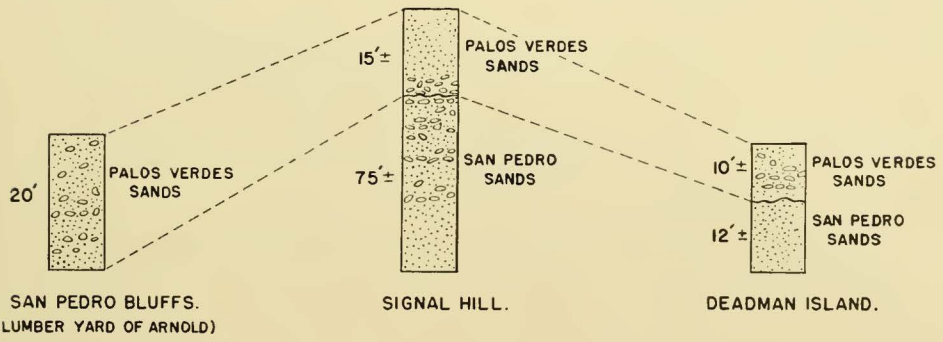

FIG. 4

CORRELATION OF THE SAN PEDRO AND PALOS VERDES SANDS AT SIGNAL HILL.

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